NEGATIVE PRESSURE PARTICULATE RESPIRATORS THEIR OPERATION AND CERTIFICATION HISTORY

Ref: (a) U.S. Department of Labor, Mine Safety and Health Administration, Mining History, Museums and Disasters website http://www.msha.gov/history.htm
(b) Held, Bruce J.: History of Respiratory Protective Devices in the U.S., University of California, Lawrence Livermore Laboratory, California (Written under the U.S. Energy Research & Development Administration contract number W-7405-Eng.-48)
(c) PHONCON NIOSH Dr. C. Coffee/NAVENVIRHLTHCEN Mr. D. Spelce of 13 Sep 2001

INTRODUCTION:

When discussing the history of particulate respirator certification, reflection upon the history of the Bureau of Mines is essential because these two histories are strongly intertwined. The Bureau of Mines instituted the first respirator certification schedules in America.

The Federal Government established the Bureau of Mines in response to public outcry over alarmingly hazardous mining conditions. From the years 1900 to 2002, 127,920 miners were killed in coal mining and metal/nonmetal mining disasters (http://www.msha.gov/stats/charts/chartshome.htm).

Figure 1, from reference (a), shows mine rescuers conferring at a barricade behind which they found surviving miners after a mine explosion in Briceville, Tennessee on 9 December 1911. This barricade was piled up to the mine ceiling before rescuers tore it down. Notice that they are very intently observing their canary's reaction to the atmosphere. Canaries alarmed miners and mine rescuers of inhalation hazards inside the mines. Canaries would visibly show distress and sway on their perches in the presence of low concentrations of carbon monoxide and other gases before toppling over.

It was not just mining disasters killing miners. Every year 1,500 miners die from "Black Lung" disease caused by inhalation of coal dust. To help put this number of Black Lung disease deaths in perspective, there were 1,500 lives lost as result of the Titanic sinking. Adults were not the only casualties. Miners started to work as young as eight years old (Figure 2, from reference (a)).

To aid the mining and mineral industry with health and safety problems the Secretary of the Interior, in 1907, established the Technologic Branch in the U.S. Geological Survey. Then in 1910, Congress removed the Technologic Branch from the U.S. Geological Survey and established the Bureau of Mines within the Department of the Interior. The Bureau of Mines' mission was to reduce the distressing number of fatalities and injuries in coalmines.

Early Evolution of Respirators:

The Bureau of Mines developed technology to minimize mine accidents, primarily from coal dust and methane gas explosions. The mining equipment industry refined and marketed many of the technologies developed by Bureau of Mines. According to reference (b), two Bureau of Mines engineers (John Ryan and George Deike) created the Mine Safety Appliances (MSA) Company in 1914. Figure 3, from reference (b), is a closed circuit, self-contained breathing apparatus (SCBA), which was developed for mine rescue. This picture was originally from an advertisement in the 1917 MSA catalog.

According to reference (b), Schedule 14 for gas masks went into effect in August 1919, however, the Bureau of Mines didn't start approving particulate filtering respirators until 1934 when schedule 21 was promulgated and it wasn't until 1944 that chemical cartridge respirators started being approved under schedule 23. Nevertheless, prior to that time, particulate filtering respirators and chemical cartridge respirators were manufactured and sold - they were just not certified. There were many interesting devices designed during the early evolution of respirators as shown in figures 4 through 6 from reference (b). Figure 4 and figure 5 show half mask and full face particulate filtering respirators from the 1917 MSA Catalog. Figure 6 is a 1923 Wilson dust respirator, which used a sponge for a filter. When it became dirty, the sponge could be rinsed out and reused. Figure 7 is a picture of a 1929 American Optical organic vapor respirator. Can you imagine what kind of sound was produced by exhaling through this large rubber exhalation valve?

The Bureau of Mines experimented with many respirator designs. Figure 8 is a 1924 creation of the Bureau of Mines, called the Kilman's cap-style dust respirator. The filter was worn on the top of the head. This provided quite a large surface area for the filtering media. For some reason this design did not catch on with the public.

Mine Rescue and World War I:

The Bureau of Mines was very active in mine safety in other ways in addition to respirator certification testing and approval. The Bureau of Mines had their own mine rescue teams. Figure 9, from reference (a), shows two mine rescuers prepared for a mine rescue operation and equipped with a canary in what was called a "resuscitation" cage.

Figure 10, from reference (a), is a picture of a 1926 Bureau of Mines device for demonstrating the effect of carbon monoxide on canaries. Is this sort of like calibrating canaries?

In March 1917, the War Gas Investigations Branch was established in the Bureau of Mines to research use of toxic gas as an instrument of war and to develop chemical warfare defense. However, this was short lived. President Wilson transferred the laboratories set up for the Bureau of Mines to the War Department and on 28 June 1918, the War Department established the Chemical Warfare Service, which was given full responsibly for toxic chemical warfare and defense. Figure 11, from reference (b) shows a variety of World War I military gas mask designs.

Following these events, the Bureau of Mines returned to its primary mission of mine safety research and on 5 March 1919 established Schedule 13 for certifying Self Contained Breathing Apparatus for mine rescue. The cover of this first respirator schedule is show in Figure 12 (courtesy of Don Campbell, from NIOSH).

First Respirator Approvals and a Scandal:

Bureau of Mines issued its first respirator approval to the Gibbs respirator manufactured by MSA on 15 January 1920. The approval number was BM-1300, for the first SCBA approved under Schedule 13. The Gibbs respirator, shown in Figure 13, from reference (b), was a closed circuit SCBA that operated on compressed oxygen and a soda lime scrubber to remove carbon dioxide.

The Bureau of Mines was successfully accomplishing its mission until 1925 when it encountered an obstacle. In this year, as result of the Teapot Dome Scandal (Figure 14), the Bureau of Mines was transferred to the Department of Commerce. Albert Fall, the Secretary of the Department of Interior, made a secret arrangement in which the U.S. naval petroleum reserve at Wyoming's Teapot Dome was leased without competitive bidding to a private oil company. Secretary Fall received $400,000.00 in bribes and loans. More information is available concerning this issue at the following websites: http://www.govexec.com/dailyfed/0902/091602lj1.htm and http://www.msoa.com/teachers/Mr_Y/enron/Teapot1.htm

The American public was very upset over this long and drawn out investigation. Secretary Fall was found guilty of bribery; fined $100,000.00; and sentenced to one year in jail. Through guilt by association, the Bureau of Mines also suffered. It was transferred to the Department of Commerce and its funding was progressively cut. After America’s emotions cooled down over this incident, the Bureau of Mines was returned to the Department of the Interior in 1934.

30 CFR 14, SCHEDULE 21 OF 1934 - DUST, FUME, AND MIST RESPIRATORS:

In 1934, the Bureau of Mines established Schedule 21 for testing and certifying respirators equipped with filters designed to provide protection against inhalation of dusts, fumes, and mists. Certification testing was conducted at the Pittsburgh Experiment Station. Between 1934 and 1995, Schedule 21 was modified five times. The original Schedule 21 tested and certified the following types of particulate filtering respirators:

Type A respirators were protective against mechanically generated dusts, such as dust clouds produced in mining, quarrying and tunneling operations and various industrial grinding, crushing, and mineral processing.

Type B respirators protected against fumes of metals, such as lead, manganese, copper, chromium, iron, antimony, and arsenic resulting from condensation of their vapor or from chemical reactions between their vapors and gases.

Type C respirators provided protection against mists produced by spray painting, chromic acid mists from plating, and mists of other materials whose liquid does not produce harmful vapors.

Types AB, AC, etc. were combinations of Types A, B, and C.

Type D filters were approved as protection against dusts, fumes, and mists.

Figure 15 (courtesy of Don Campbell, from NIOSH) is a picture of test subjects after one of the "Man Tests" called the coal dust test. The coal dust test consisted of three men with full, average, and lean facial features exercising in a room containing a visible atmosphere of airborne powdered bituminous coal. The test subjects alternated walking at the rate of 3.5 mph for five minutes with sitting five minutes for a total of 30 min. At the end of the test, forced nasal discharge, sputum, nasal cavities and the part of the face covered by the respirator must not show appreciably more visible coal dust than similar observations made before entering the coal dust atmosphere. The men on the left and on the right of this photograph show evidence of mask leakage where their respirators did not properly seal to their faces. The leakage formed a visible streamline of coal dust proceeding toward their nostrils. This testing procedure was used from 1934 until 1972.

Mechanical Airflow resistance of the complete respirator assembly was tested at the flow rate of 85 lpm (liters per minute), which is the same flow rate as today's certification tests for single filters specified in 42 CFR 84. Like today's certification standard, exhalation resistance could not exceed 25 mm H_2O. In contrast, the inhalation resistance could be as high as 50 mm H_2O as compared with the present 35 mm H_2O maximum requirement.

Respirators approved as Type A for dust were mechanically tested at 32 lpm in an atmosphere of 0.6 micron sized free silica produced from ground flint. There were two tests: High Dust and Low Dust Concentration Tests. In the High Dust Test, three respirators were tested for three 30-minute periods in a 50 mg/m^3 silica atmosphere. Leakage could not exceed 9 mg for the three respirators or 4 mg for any one of them. In the Low Dust Test, three respirators were tested for two 156-minute periods in a 5 mg/m^3 silica atmosphere. Leakage could not exceed 30 mg for the three respirators or 12 mg for any one respirator.

There were two types of Type B Fume Respirators - “Low Filter Plugging Fumes” and “Fast-Plugging Fumes.” Low filter plugging fumes such as lead, manganese, copper, and chromium fume do not cause appreciable increase in filter airflow resistance. These respirators were mechanically tested at 32 lpm in an atmosphere of 15 mg/m^3 lead oxide fume produced by decomposition and combustion of tetraethyl lead. Leakage in each respirator could not exceed 1.5 mg. Fast-plugging fumes included magnesium, zinc, cadmium, aluminum, and antimony, which significantly increase filter resistance. Fast-plugging fume respirators first had to pass the Low-Plugging Fumes Test, and then pass an additional test. In this test, three respirators were tested at 32 lpm in 100 mg/m^3 magnesium oxide produced by burning magnesium ribbon. These respirators were tested until 200 mg magnesium oxide was pulled through the filters. Then they had to pass the mechanical airflow resistance Test with maximum inhalation and exhalation resistance of 50 and 25 mm H_2O, respectively.

Type C Mist Respirators had three tests. In the Chromic Acid Mist Test, respirators were tested at 32 lpm in 15 mg/m^3 chromic acid mist produced by electrolyzing an aqueous solution of chromic acid. Three respirators were tested for two 156-minute periods. Leakage could not exceed 1 mg for any one respirator. Passing this test would gain chromic acid mist approval. For approval as protection against all mists, the next two tests had to be passed.

Lead-Paint Mist Test:

> Respirators were tested at 32 lpm in 300 to 600 mg/m^3 lead spray paint mist. Three respirators were tested for two 156-minute periods. Leakage could not exceed 1.5 mg lead for any one respirator.

Water-Mist, Silica Dust Test:

> Respirators were tested at 32 lpm in 10 mg/m^3 aqueous silica mist. Three respirators were tested for two 156-minute periods. Leakage could not exceed 5 mg silica for any one respirator.

30 CFR 13, Schedule 14E of 1941 - Gas Masks:

Gas masks are mentioned because they were often approved with particulate filters. Schedule 14 had been around since August of 1919 and had been modified eight times over the years, but the information discussed here is from the 1941 version, Schedule 14E. Besides being tested for gases and vapors, the respirators with particulate approvals had to meet the Schedule 21 requirements for dusts, fumes, and mists. In addition, the canisters had to filter out “specially prepared” tobacco smoke when exposed to an 85 lpm simulated breathing rate. Schedule 14 did not state how to prepare the tobacco smoke but it referenced a 1926 Bureau of Mines Technical Paper on how to prepare it.

Two separate man tests had to be passed for particulate approval. In the first test, two men performed exercises in a 1,000 cubic foot room filled with smoke from one pound of cotton waste burning in a smudge pot. To pass the 10-minute test, no respiratory or eye discomfort or irritation could be experienced.

In the second test, a 20-minute test, two men had to perform exercises in a 500 ppm tin tetrachloride atmosphere without experiencing irritation of the eyes and respiratory system. Tin tetrachloride reacts with the moisture in the respiratory system to form hydrogen chloride, which is very irritating.

30 CFR 14A, Schedule 23 of 1944 - Non-emergency Gas Respirators:

Schedule 23 is mentioned because particulate filters were approved in combination with many organic vapor respirators. On 13 November 1944, the Bureau of Mines published Schedule 23 for organic vapor respirators worn as protection against non-immediately dangerous to life or health (IDLH) atmospheres of organic vapors up to concentrations of 1,000 ppm or 0.1%. As implied above, the 1944 version of this standard was limited in scope to only organic vapor respirators. These combination cartridge/particulate filtering respirators had to pass some interesting tests as described below.

This schedule approved two types of respirators: Type B and Type BE. Type B respirators were approved for protection against organic vapors only. Cartridges were tested for their efficacy against a challenge concentration of 1,000 ppm carbon tetrachloride.

> Type BE respirators were approved for protection against organic vapors and dusts, fumes, and mists.
>
> > The BE respirators had to pass the Type A, B, C, or D tests under schedule 21 for dusts, fumes and mists.

In addition, two man tests were conducted for the organic vapors. The first was a "tightness test" where two men exercised while wearing the respirators in 100 ppm isoamyl acetate, which was similar to the current qualitative banana oil fit test.

In the second test, the respirators were tested against a 5,000 ppm carbon tetrachloride atmosphere in which two men wore the respirators until the odor of carbon tetrachloride was detected inside the respirator. A series of exercises were performed including the one shown in Figure 16, from reference (b), in which the test subjects pumped air with a hand operated tire pump into a one cubic foot cylinder to a pressure of 25 psi. The chemical cartridges had to last at least 30 minutes to pass the test. Even though the test was performed under high concentrations, approval was still granted for organic vapor concentrations not exceeding 1,000 ppm. To speed up the test by about five times, 5,000 ppm carbon tetrachloride was used instead of 1,000 ppm. NIOSH now considers 200 ppm carbon tetrachloride as IDLH. Therefore, these man tests were conducted in 25 times the current IDLH concentration for carbon tetrachloride!

30 CFR 14, SCHEDULE 21A, OF 1955 - REVISED DUST, FUME, AND MIST RESPIRATORS:

In 1955, Schedule 21 was revised to Schedule 21A. For the first time, single use respirators were approved. Unlike reusable respirators in which filters could be changed, single use respirators were designed for disposal after use. There were two classes of single use respirators.

* Single use respirators approved against nuisance dusts and dusts producing pneumonoconiosis, but not approved for protection against fumes.

  Pneumonoconiosis is a disease of the lungs caused by the habitual inhalation of mineral or metallic particles.

* Single use respirators approved against dusts that were no more toxic than lead.

Schedule 21A also included certification testing for respirators with replaceable filters for protection against the inhalation hazards listed here.

* Pneumoconiosis producing and nuisance dust
* Toxic dust
* Dusts
* Fumes
* Silica mist
* Chromic acid mist
* Combination approval

The facepieces of all respirator categories had to pass a pressure tightness test by a panel of 15 to 20 men having a variety of facial shapes and sizes (Note that none of the testing requirements from 1919 through 1955 included women.). The pressure tightness test is simply the positive and negative user seal checks that are currently required by OSHA (Occupational Safety and Health Administration) in paragraph (g)(1)(iii) of their Respirator Standard, 29 CFR 1910.134 to be performed each time that a tight fitting respirator is donned to ensure that the mask is properly seated to the face.

Each respirator category had to pass the Coal Dust Test described in Schedule 21 of 1934. Respirators approved as protection against fumes were equipped with organic vapor cartridges and 15 to 20 men had to pass an isoamyl acetate (banana oil) fit test.

30 CFR 14, Schedule 21B OF 1965 - SECOND REVISION OF DUST, FUME, AND MIST RESPIRATORS:

In 1965, Schedule 21B was published, which included categories of both low efficiency and high efficiency particulate filtering respirators. The facepieces of all respirator categories had to pass a pressure tightness test by a panel of 15 to 20 people having a variety of facial shapes and sizes (Note that the requirement changed from a panel of "men" in 1955 to a panel of "people" in 1965.). As mentioned in the last section, the pressure tightness test is simply positive and negative user seal checks. In addition, each respirator category had to pass the Coal Dust Test described earlier. The categories included the following types of particulate respirators:

<u>Low Efficiency Respirators:</u>

There were three categories of low efficiency respirators approved as protection against dusts, fumes, and mists with TLVs (Threshold Limit Values) **greater than 0.1 mg/m^3**.

* Dusts included asbestos, coal, and silica.

* Fumes included antimony, arsenic, manganese, and cadmium.

* Mists included chromic acid mist and enamel spray coating.

Tests were similar to those discussed under the 1934 Schedule 21 approval including a Silica-Dust and Silica-Mist Test.

<u>High Efficiency Respirators:</u>

The first certified high efficiency particulate air (HEPA) filters were approved for protection against dusts, fumes, and mists with TLVs **less than 0.1 mg/m^3** or up to 10, 100, or 1,000 times the TLV for radionuclides. Filters were mechanical tested and had to be 99.97 percent efficient against 0.3 micron sized dioctyl phthalate (DOP) aerosol. This DOP Filter Test had the same passing criteria as the DOP Filter Test for HEPA filters set forth in 30 CFR Part 11, which was promulgated in 1972.

Filters approved for protection against dusts, fumes, and mists with TLVs less than 0.1 mg/m^3 had to pass 90 minute, Lead Dust, Lead Fume, and Chromic Acid Mist Tests.

Radionuclides are isotopes that emit radiation resulting in formation of new nuclides. Examples include: uranium and thorium. Respirators approved for protection against radionuclides had to pass a 0.2 micron uranine mechanical test. Uranine is a water-soluble, yellow-green dye. Respirators approved as protection against radionuclides also had to pass man tests, which included isoamyl acetate fit tests, and DOP quantitative fit tests. (The National Toxicology Program latter found that DOP may be carcinogenic. Corn oil and polyalphaolefin are now used for quantitative fit testing.)

There was an interesting requirement for high efficiency filtered respirators in which the exhalation valves must be provided with a dead-air space or other means to prevent inward leakage of contaminated air during inhalation. Valve covers were required to provide this dead-air space to trap the last portion of exhaled breath inside the valve cover. During the next inhalation, any leakage around the exhalation valve would cause this small pocket of exhaled breath inside the exhalation valve cover to be inhaled instead of contaminated air. In contrast, if the respirator design excluded an exhalation valve cover, the air immediately surrounding the valve would be contaminated workplace air, which would be inhaled if the valve didn't close immediately after exhalation. This requirement was changed in 30 CFR 11 to "Exhalation valves shall be … designed and constructed to prevent inward leakage of contaminated air."

Although HEPA filters were first approved in 1965, Arthur D. Little designed the very first HEPA filter during the WW-II, Manhattan Project for protection against 0.3 micron sized radioactive particles. The condensation of radioactive iodine was considered the most harmful solid particle and was identified as being 0.3 microns in size. 0.3 micron sized particles are in the size range that penetrates filters most easily.

30 CFR 14, AMENDED SCHEDULE 21B OF 1969 - DUST, FUME, AND MIST RESPIRATORS AMENDED:

On 19 June 1969, 30 CFR 14, Schedule 21B was modified to include filters for protection against radon daughters. These respirators had to pass a 312-minute, Lead Fume Test. Radon is a radioactive gas, associated with underground mining industries, which decays into polonium, lead, and bismuth radioactive isotopes, which emit alpha particles. Radon daughter particles easily attach to airborne dust, smoke, and mist, which are fine enough to reach the deepest parts of the lungs when inhaled.

Maximum inhalation pressure and exhalation pressure for other particulate respirators was 50 and 20 mm H_2O, respectively. However respirators approved for radon daughters could not exceed 18 mm H_2O inhalation pressure and the exhalation pressure could not exceed 15 mm H_2O. Decreased inhalation and exhalation pressure requirements were probably considered necessary for miners, whose pulmonary functions were already challenged.

Related to the issue of decreasing respirator breathing resistance for miners, this 1969 amendment introduced provisions for approving the first powered air purifying respirators (PAPRs). PAPRs were approved for protection against radon daughters and radon daughters attached to dusts, fumes and mists. PAPRs, which greatly reduce breathing resistance, had to pass the Lead Fume and Silica Dust Tests with minimum air flow through the filters of at least four cfm for tight fitting facepieces and six cfm for helmets and hooded respirators.

30 CFR Part 11 of 1972 - COMBINATION OF ALL RESPIRATOR APPROVAL SCHEDULES:

On 25 March 1972, 30 CFR Part 14 was replaced by 30 CFR 11, when the National Institute for Occupational Safety and Health (NIOSH) started jointly approving respirators with the Bureau of Mines. The previously separate respirator schedules for SCBA, airlines, gas masks, chemical cartridge respirators, and particulate respirators were combined under 30 CFR 11.

In 1973, the regulatory portions of the Bureau of Mines were transferred to the Mining Enforcement and Safety Administration (MESA), under the U.S. Department of the Interior and respirator approvals were issued jointly by MESA/NIOSH. The approval schedules for Bureau of Mines respirators have expired and are not considered valid except in the following two cases:

* Gas masks approved by the U.S. Bureau of Mines (Schedule 14F) are approved until further notice.

* SCBA approved under Schedule 13E which have a low air warning device and which were purchased before June 30, 1975 are still valid.

In 1977, the regulatory portions of MESA were transferred to the Mine Safety and Health Administration (MSHA) under the U.S. Department of Labor. Approvals were then jointly issued by NIOSH/MSHA.

30 CFR 11 contained certification testing criteria for both low efficiency and high efficiency dust, fume, and mist respirators with replaceable filters; respirators for protection against radon daughters; and single use respirators.

<u>Low Efficiency Respirators:</u>

Low efficiency respirators with replaceable or reusable filters were approved as protection against dusts, or mists, or fumes with permissible exposure limits (PELs) **not less than 0.05 mg/m^3**.

Approved dust and/or mist respirators were 99 percent efficient against 0.4 to 0.6 micron sized silica dust or mist aerosols.

Approved fume respirators were 99 percent efficient when tested against lead fumes smaller than 1 micron.

Most manufacturers had their fume filters approved for dusts, fumes and mists because if the filters could pass the fume certification tests then they would certainly pass the dust and mist tests. Some respirators were also approved for protection against radon daughters. Many fume grade filters were once approved for protection against asbestos, but their use is no longer permitted under the OSHA asbestos standards, which require HEPA filters.

High Efficiency Particulate Air Respirators:

30 CFR 11 contained certification testing criteria for HEPA respirators used as protection against dusts, fumes, and mists with PELs **less than 0.05 mg/m^3**.

HEPA respirators were also approved as protection against radionuclides. HEPA filters had to be at least 99.97% efficient against 0.3 micron DOP particles. They were also tested against silica dust and mist.

Mechanical HEPA filters increase the filter's surface area, usually by folding or pleating. Because of increased breathing resistance, HEPA filters could not pass the low breathing resistance requirements for asbestos and radon daughter certification. However, NIOSH has written a Respirator Users Notice stating that HEPA filters were intrinsically approved as protection against asbestos and radon daughters.

Radon Daughter Respirators:

Respirators approved as protection against radon daughters had to pass the Silica Dust and Silica Mist Tests and were required to have very low breathing resistance. These respirators probably required low breathing resistance because the workers whom NIOSH anticipated wearing them already had compromised pulmonary functions from previous occupational exposure.

Respirators for Asbestos:

Asbestos approved respirators also had the same requirements as those of the radon daughters including low breathing resistance probably because the workers wearing them already had compromised pulmonary functions from previous occupational exposure.

Single Use Respirators:

Single use (or disposable) respirators were approved as protection against pneumoconiosis and fibrosis producing dusts (Fibrosis is abnormal formation of fibrous (scar) tissue.), or dusts and mists, including, but not limited to aluminum, asbestos, coal, flour, iron ore, and free silica. Some Single use respirators were approved for asbestos but the current OSHA Asbestos Standards specifically prohibit using single use dust respirators for asbestos work. The minimum respirator allowed for protection against asbestos is a half mask with HEPA filters.

Single-use dust/mist respirators were 99% efficient against silica dust and mist particles 0.4 to 0.6 microns in diameter. Single-use respirators could be used until the filter becomes hard to breathe through or the filter became damaged. Then the entire respirator was discarded.

42 CFR 84, of 1995 - NIOSH RESPIRATOR CERTIFICATION PROCEDURES:

Background:

On 10 July 1995, the respirator certification regulation, 30 CFR 11, was replaced by 42 CFR 84. Under 42 CFR 84, respirators are approved only by NIOSH except respirators used in underground mining operations; then they are required to be approved by both NIOSH and MSHA. Both NIOSH approved and NIOSH/MSHA approved respirators are authorized for use.

In 1995, only the particulate, non-powered air-purifying class of respirators was updated under 42 CFR 84. Manufacturers could sell particulate filters approved under 30 CFR 11 until 10 July 1998. Distributors and users could continue to sell and use Part 11 particulate filtering respirators until their supplies were exhausted.

> Note: NIOSH issued a Respirator Users Notice on 4 September 2002 recommending discontinued use of respirator particulate filters and combination filters approved under 30 CFR Part 11. NIOSH stated that some of these filters were deteriorating and may not meet the performance requirements of 30 CFR Part 11. NIOSH recommended switching to the filters approved under 42 CFR 84, which meet improved filtration criteria. More details concerning this issue are provided in the Respirator Users Notice at the following NIOSH website: http://www.cdc.gov/niosh/npptl/run_040902.html

30 CFR 11 approval labels for particulate filtering respirators displayed NIOSH/MSHA emblems and had the certification number sequence TC-21C-XXXX. Particulate respirators approved under 42 CFR 84 have the approval number sequence of TC-84A-XXXX and the approval labels bear the NIOSH and Department of Health and Human Services emblems. Chemical cartridge and airline respirators that include particulate filter elements also have labels indicating the new particulate filter classification, TC-84A-XXXX.

Classification of Negative Pressure Particulate Respirators:

Under 42 CFR 84 there are nine classifications of particulate air purifying respirators. NIOSH now certifies respirators under three classes of filters: N, R, and P and three filter efficiencies: 95, 99, and 100. The filter efficiencies equate to the percentage of particles removed from the air during NIOSH certification testing. For example: 95% efficiency means that during certification testing 95% of the challenge particles were removed and 5% passed through the filter.

The 100 filters actually remove 99.97% of the challenge particles - not 100%. OSHA's Respirator Standard, 29 CFR 1910.134, states that N, R, and P 100 filters are considered HEPA filters. All nine particulate filtering respirator classes can be used as protection against TB in health care facilities.

Filters approved under 42 CFR 84 can be used without workplace particle size analysis because NIOSH certification testing criteria simulates the "worst-case" respirator use scenario, which includes testing twenty filters:

* Using non-charged aerosols, which are very rigorous challenge agents for electrostatically charged filters;

* Challenging filters with very high air flow rates, which simulate exceptionally high work rates - 85 liters/min for single filters and 42.5 liters/min for pairs of filters;

* Challenging filters against a very high loading concentration - the challenge concentration is 200 mg/m^3; and

* Testing filters against the most filter penetrating sized aerosols.

The classes of filters are largely defined by their degradation to oil aerosols. Oils tend to degrade filter efficiency. Oils are defined as hydrocarbon liquids with high boiling points, high molecular weights, and low vapor pressure. Oil aerosols can consist of mineral, vegetable, animal and synthetic substances that are slippery, combustible, and soluble in organic solvents such as ether but not soluble in water. A partial list of filter degrading oils includes mists from the following oils: alboline; white mineral oil; bayol F; blandlube; drakeol; paraffin oil; liquid petrolatum; water-insoluble petroleum-based cutting oils; heat-treating oil; hydraulic oil; lubricating oil; drawing oil; crystol 325; cable oil; drawing oil; engine oil; heat-treating oils; dioctyl phthalate; corn oil; and transformer oil.

Per reference (c), N filters are tested against a 0.2 micron mass median aerodynamic diameter (MMAD) sized NaCl aerosol with a count median diameter of 0.075 microns (MMAD is based on weight and count median diameter is based on size. In both, 50% of the particles will be smaller and 50% will be larger than the median number.). NaCl is only slightly degrading to the filter. N filters cannot be used in atmospheres containing oil aerosols. N filters have no service time limitation in most workplace settings but in high particulate concentrations the N filters use cannot be extended beyond 8 hours unless evaluated by the employer to prove that the integrity of the filters do not degrade or that the total mass loading of the filters is less than 200 mg.

R filters only have service time limitations when used as protection against oil degrading atmospheres. R filters cannot be extended beyond 8 hours of use in an oil aerosol atmosphere unless evaluated by the user to prove that the integrity of the filters does not degrade or that the total mass loading of the filters is less than 200 mg.

Per reference (c), both R and P filters are tested against a 0.3 micron MMAD sized DOP aerosol with a count median diameter of 0.185 microns.

P100 filters were originally approved to be used in oil degrading atmospheres and had no time limitations. However, the NIOSH Respirator User Notice of 2 May 1997 stated that long-term oil exposure resulted in the reduction in efficiency of P100 filters to efficiencies much less than P95 filters. NIOSH has requested each manufacturer of P-series filters to establish service time recommendations as part of their user instructions. More information concerning this issue is available at the following website: http://www.cdc.gov/niosh/pseries.html.

Filter Change Out Schedules:

OSHA does not require establishing change out schedules for particulate respirators. However, since N and R filters must be replaced before 200 mg loading is reached, then change out schedules can be calculated if we know the workplace concentration and the daily breathing volume. NIOSH estimates that a typical worker inhales 10 m^3 air per day. This equates to a 20 lpm breathing or work rate. This information can be used to determine when N and R filters will become loaded with 200 mg.

For example: What is the estimated filter change out schedule for an operation in which the Upper Tolerance Limit ($UTL_{95\%, 95\%}$), was 8 mg/m^3 for total dust (Particulates Not Otherwise Regulated)? The $UTL_{95\%, 95\%}$ is the concentration below which we are 95 percent confident that 95 percent of exposures lie. Since no oil is present, a half mask respirator equipped with N95 filters was selected for protection.

Calculate daily filter loading by multiplying 8 mg/m^3 exposure by the 10 m^3 air/day breathing volume. This equals 80 mg/day.

Next, calculate how many days it takes to load 200 mg on the filters by dividing 200 mg by 80 mg/day.

This equals 2.5 days; therefore, change filters every 2 ½ days or earlier if breathing starts to be difficult or filters become damaged or unsanitary. This same logic can be applied to R filters to estimate service life and establish filter change out schedules. If P filters are used, replace them according to respirator manufacturer's recommendations.

Filter Color Coding:

ANSI Z88.7-2001 replaces ANSI K13.1-1973 as the current Color Coding Standard for Air-Purifying Respirator Canisters and Filters. P100 filters and HEPA filters for powered air purifying respirators are purple. Z88.7 uses the HE abbreviation for "High Efficiency" instead of HEPA. Orange was selected for P95, P99, R95, R99, and R100 filters. Orange was the previous color coding for dust/fume/mist filters. Teal was selected for N95, N99 and N100 filters. Combination chemical cartridges with particulate filters have stripes indicating the type of particulate filter. An abbreviated version of the color coding table in ANSI Z88.7 is provided in Figure 17.

Particulate Capture Mechanisms:

On inhalation, particles are drawn into the fibrous filter along with the air in which they are suspended. Particles are then trapped by the fibers. The probability that a fiber will capture a particle is dependent on:

* Fiber size and density;
* Particle size and shape;
* Particle velocity;
* Electrical charge of the particle and filter fiber.

Filters cannot be designed for 100% efficiency - the breathing resistance would be too great. Consequently, filter design is based on a combination of particulate filtration mechanisms. Filters are very efficient at filtering very large particles by sedimentation, impaction, and interception and very small particles by diffusion. These mechanisms are illustrated in Figure 18.

Sedimentation:

Only very large particles (2 microns and above) are affected by sedimentation. Sedimentation works only at low air flow rates. As particles fall through the airstreams by the force of gravity, they are captured by the fiber.

Impaction:

Impaction is primarily a function of the particles' momentum or inertia and usually occurs when the airstream velocity is high and the particles are relatively large (greater than 1 micron diameter) and heavy. Since particles with high mass and velocity have more momentum, they cannot bend with the airstreams as air flows around the fiber, so the particles impact onto the fiber.

Interception:

Particles stay in the airstreams but are pulled onto the fiber by van der Waal's and electrostatic forces. Interception affects particles that are between one half and one micron in diameter and that are lighter in weight than those affected by impaction. While flowing through the filter, particles of this magnitude approaching within a distance of half of their diameters will be captured by the fibers. Filtration efficiency is enhanced by high relative humidity because the moisture forms a liquid meniscus between the particles and fibers, which assures adhesion.

Diffusion:

Smaller particles (less than 0.2 microns diameter) with slower velocities are captured by diffusion. Small particles are subject to Brownian movement (the random movement or bouncing motion of small molecules, almost like vibration), which increases the probability that the particle will contact another object. Slower velocity means the particle remains near the filter for a longer time, which increases the probability that the particle will contact the fiber and be captured. This is the main mechanism used in high-efficiency particulate air filters and is usually accomplished by pleating the filter, which has a tendency to increase breathing resistance.

Electrostatic Attraction:

Charged particles in the airstreams are attracted by oppositely charged fibers. Electrostatic attraction is often used to increase filter efficiency for capturing particles that are less than one micron in size without significantly increasing breathing resistance. There are two basic methods of establishing electrostatic attraction in filters. The original method consisted of impregnating a blend of wool and synthetic fibers with wood resin, which is then dried and energized by a mechanical needling process. This creates a positive charge on the fibers and a negative charge on the resin. Unfortunately, this mechanism is not effective for oil mist or atmospheres with high humidity, which dissipate the electrostatic charge.

In the newer method, electret fibers have permanent, strong electrostatic charges embedded inside the fibers during processing. Fibers maintain a positive charge on one side and a negative charge on the other side. Besides attracting oppositely charged particles to them, electret fibers polarize neutral particles by attracting the oppositely charged dipole to the fiber. Electret fibers are less affected by high humidity, heat, and oily particles than fibers treated by the original method.

Filter Efficiency Versus Particle Size:

As shown in Figure 19 (Figures 18 through 23 are courtesy of Tom Nelson, from Nelson Industrial Hygiene Services, Inc.), large particles are filtered by impaction and interception, while very small particles are filtered by diffusion. Particles 0.1 to 0.4 microns in size are the most filter penetrating size because these median sized particles are too small for effective interception and too large for effective diffusion filtering mechanisms.

Higher efficiency filters don’t necessarily increase protection. NIOSH tests filters under worst case conditions of the most penetrating particle sizes and at a very high flow rate simulating very heavy work that could not be sustained more than brief periods of time. As shown in Figure 20 and explained above, the worst filter efficiency is around 0.2 micron sized particles. However, for particles of this size the filters are still 95%

efficient. As illustrated in Figure 20, the filters are more than 99% efficient on either side of the 0.2 micron dip in efficiency.

Increasing filter efficiency also increases inhalation pressure. The data in Figure 21 was made using a controlled negative pressure fit test apparatus. This data shows that leakage around the facepiece seal increases with increased inhalation pressure.

Figure 22 shows that 95 percent filters are 95% efficient when tested by NIOSH at 85 liters per minute. 85 liters per minute is a work rate that could not be sustained very long. Work rates realistically expected in the workplace are 20 to 30 lpm. At these lower breathing rates, 95 percent filters are between 98 to 99% efficient. Figure 23 shows that typical particle size in industry is much larger than the 0.1 to 0.4 micron size range that penetrates filters most effectively. These large particles are filtered out with greater than 99% efficiency by 95% filters.

Because particle sizes in much of industry are large and the work rates commonly encountered in industry are relatively low, 95% filters that pass NIOSH certification testing will be essentially 100% efficient in most workplaces. Using a higher efficiency filter where it is not needed could actually increase exposure by increasing breathing resistance pressure and causing more leakage around the sealing surface. Therefore, protection against carcinogens and other highly toxic inhalation hazards does not always require the use of HEPA filters.

However, hazard analysis must always be performed for respirator selection because there may be scenarios where N, R, or P 100 filters may be necessary. An example of such as a case would be where: 1) the contaminant particle size is the most penetrating; 2) the hazard ratio (concentration of contaminant divided by its occupational exposure limit) is close to the assigned protection factor of the respirator; and 3) the breathing rate is very high. Also, compliance with OSHA chemical specific standards, such as lead, asbestos and cadmium, requires wearing HEPA filters.

Filter Problems During Welding:

There is special matter that must be taken into consideration during the process of selecting particulate filtering respirators for welding operations, which is the sparks produced during welding can enter filters and set the filtering media on fire (Figure 24, courtesy of Mark Haskew, from Department of Energy). Respirator manufacturers make specially designed filters to prevent sparks from entering into the filter media. There are also plenum respirators with the filters worn on the back to avoid sparks.